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APPLICATION OF ELECTROMAGNETIC ABSORBING
MATERIALS AS INTERFERENCE REDUCTION TECHNIQUES

Interim Engineering Report
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Rome Air Development Center
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Air Force Systems Command
Griffiss Air Force Base, New York

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(Prepared under Contract No. AF 30(602)-2711 by The Antenna Laboratory, Department of Electrical Engineering, The Ohio State University Research Foundation, Columbus, Ohio)

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FOREWORD

The research reported herein was performed in the Antenna Laboratory, Department of Electrical Engineering, The Ohio State University, under Contract No. AF30(602)-2711 between the Ohio State University Research Foundation and Rome Air Development Center, Air Force Systems Command, USAF, Griffiss AFB, N.Y. Mr. Karl Kirk of Rome Air Development Center was the contract initiator.


ABSTRACT

The use of radar absorber material is being considered for reduction of radio-frequency interference (RFI). The study of side-lobe reduction is being applied to three antenna types: the paraboloid reflector, the Luneberg lens, and the horn antenna. A method is proposed for the design of a null in the Fresnel zone for the purpose of RFI reduction with a small antenna located in the null.

PUBLICATION REVIEW

This report has been reviewed and is approved.

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INTERIM ENGINEERING REPORT

I. INTRODUCTION

Effort is being directed toward the reduction of radio-frequency interference (RFI) between antenna systems by use of radar absorber materials (RAM). The main goal essentially consists of applying such materials to reduce transmission of radio-frequency energy in undesired directions without materially affecting transmission in the desired direction.

Three major approaches are being considered which include (a) control of undesired radiation in side lobes, (b) introduction of nulls in the Fresnel region, and (c) use of absorber screens to reduce unwanted radiation. The mechanism of radiation in antenna side lobes has been reviewed for three pertinent antenna types to determine how absorber may be efficiently applied. The types of antennas being considered are: (a) the paraboloidal reflector, (b) the Luneberg lens, and (c) the horn.

The concept of introducing a null in the Fresnel zone of an antenna was introduced in a paper¹ at the Contractor Symposium at Griffiss Air Force Base in June 1962. This concept has since been extended so that the position of the null can be controlled, and the disturbances of the other properties of the antenna have been noted. A technical report is in process describing these results.⁴

Preliminary measurements have been taken on the use of a screen of absorber to reduce the radiation in some particular direction. These measurements indicate that the suggestion given at the Contractor Symposium was overly cautious. The suggestion was that an antenna could be operated in the vicinity of such a screen without significantly affecting its performance provided the panel lies outside the angle at which the first null occurs in the far field.

A method of analyzing nonuniform arrays has been described in a technical report.² Because large ground-based arrays are becoming of increasing importance, this analysis should prove useful in designing such structures for optimum side-lobe performance. Since this report has already been completed, no further description of the method is to be given in this interim report.

Anticipating that some of the measurements are to be made at extremely low levels, considerable work was done on the antenna pattern range to optimize its performance without impairing its use for ordinary measurements.

II. CONTROL OF ANTENNA SIDE-LOBE RADIATION

Each antenna type has different characteristics insofar as the undesired radiation is concerned. Thus in the succeeding paragraphs the various characteristics are discussed and their application to the specific antenna and the state of the art is indicated.

A. The Paraboloid

The paraboloid, because of its simplicity of construction and operation, is probably the most common of large directional antennas. If all classes of reflector-type antennas are included in this category, the paraboloid certainly is the most useful of the large ground-based antennas. Radiation from this type of antenna is illustrated in the hypothetical pattern shown in Fig. 1. Three types of radiation are illustrated. First, there is the desired radiation from the effective antenna aperture into the region of interest; the side lobes in this region are minimized by obtaining a proper aperture distribution. The control of the amplitude aperture distribution was developed during World War II to an adequate degree. An additional consideration for very large antennas is the accuracy with which the reflector is constructed. Accuracies of better than $\lambda/8$ are needed. Otherwise phase errors are introduced which can lead to excessively large side-lobe levels and even beam splitting. Aperture blocking by feeds can also lead to excessive side lobes for smaller reflector-type antennas. This mechanism has also received considerable attention.

A second region of the pattern of Fig. 1 is described as direct radiation from the feed. As implied, the energy in this region is radiated by the feed and is never incident on the reflecting surface. This is probably the most difficult component to control except for the very large paraboloids in which the feed could be designed to reduce such radiation with little or no attention to aperture blocking being required.

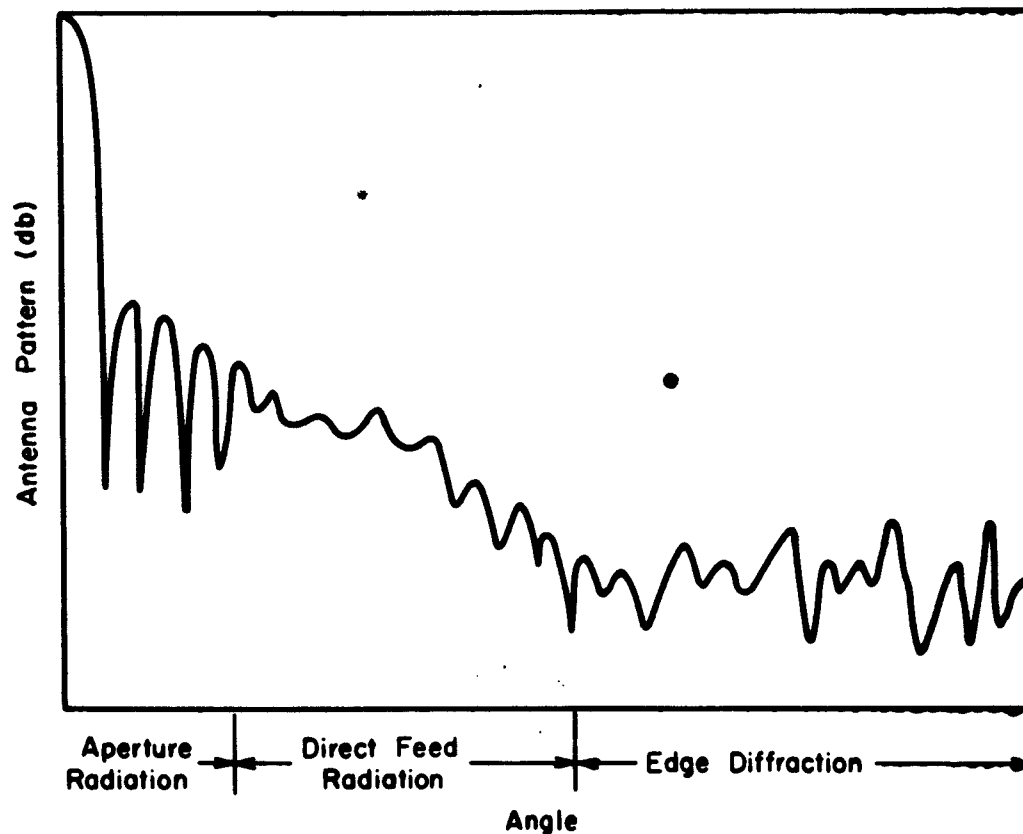


Fig. 1. Radiation regions of paraboloid reflector antenna.

The third and last region of the pattern shown in Fig. 1 is attributed to edge diffraction at the reflector rim. In this case the energy from the feed strikes the edge of the parabola and is diffracted by that edge in all directions. This is the most significant component in the back direction and may be controlled by means of absorber screens behind the paraboloid.

It is apparent from the above description that if RFI were the only problem under consideration, and if tolerances could be maintained, a very large reflector-type antenna could be designed in which nearly all of the radiation would be in the region described by aperture radiation. However, the disadvantage would be that a much larger antenna would be required to obtain a given gain than is ordinarily used. Tolerances and manufacturing costs also would appear as very significant factors. An antenna evolved from this approach would probably be competitive with

the best known low-temperature antenna, the hog horn, in not only reduced undesired radiation but also in tolerance, maneuverability, etc. Therefore, it is extremely important that the undesired radiation be reduced in as compact a manner as is possible. The use of absorbers seems to be one of the most reasonable methods for such reduction with minimum size and shape. However, in order for the use of absorbers to be practical, the resultant structure should not be unwieldy for large antennas. This immediately rules out such structures as the "tunnel" antenna. It may be noted that the tunnel antenna yields one advantage when compared with the ideal case discussed above in that no close tolerance is required in the construction of the tunnel.

A 14-inch diameter paraboloid with a focal length of 3 inches was chosen for use at X-band to study these applications, for several reasons. The chief reasons are the convenient size and frequency for experimental studies. Results obtained from this antenna can then be generalized to other paraboloids.

Several methods of sidelobe reduction have been tested on the paraboloid with two different feeds. Basically, the methods can be classified as reduction of direct-feed radiation or reduction of edge diffraction at the rim of the reflector. For cases in which direct-feed radiation is reduced in the direction of the reflector rim, edge diffraction is also reduced.

The backlobe region where direct-feed radiation is not a factor can be analyzed to a first-order approximation by the geometrical theory of diffraction.³ The backlobe region of a paraboloidal reflector has been calculated by this method, and the calculated results agree with measurements.⁴

One of the feeds employed was a waveguide double-dipole feed which is described by Silver.⁵ In one experiment, the effect of extending the reflector so that the reflector intercepts more of the feed energy was measured. A reduction of 5-10 db was obtained over the sector subtended by the reflector extension. As another method of reduction of direct-feed radiation, a metal sleeve was placed over the feed so as not to affect the illumination of the reflector. Some reduction in direct-feed radiation was indicated, but the resulting aperture blockage produced by the sleeve raised the sidelobes in other directions.

The use of absorber materials to reduce edge diffraction was measured for several configurations. A 24-inch square absorber panel was fitted to the reflector; see Fig. 2. A reduction of about 20 db in the backlobes was obtained in the E-plane for angles greater than 130° from the main beam as shown in Fig. 2. Little reduction was obtained in the H-plane because the backlobes are already low. The amount of reduction is relatively insensitive to the position of the panel behind the reflector as it is translated parallel to its original position. Slightly greater reduction is obtained for the position at the reflector rim.

Since the backlobe structure is produced mainly by edge diffraction, considerable reduction might be obtained by a small amount of absorber material appropriately placed at the reflector edge. In one test, an annular ring of $\lambda/4$ resonant absorber of $1\frac{1}{2}$ inch width was attached to the reflector rim. An increase in backlobes resulted. In another test, the absorber was folded around the reflector rim. No significant change in the patterns was noted as compared to the patterns of the unmodified reflector. A third test was made with another type of resonant absorber in which the absorber was placed tangential to the reflector and extending 1 inch beyond the rim. The only significant result was that a large reduction was obtained over a sector in the E-plane corresponding to normal incidence on the plane of the absorber.

From the previously described tests, the use of resonant-type absorber does not appear promising in the reduction of edge diffraction. The main reason is that absorption is high only for normal incidence on an undistorted section of absorber. The use of a small amount of non-resonant absorber appropriately attached to the reflector rim will be tested as a means of reducing edge diffraction.

B. Luneberg Lens Antenna

The Luneberg lens was originally thought to be an antenna for which great reduction of nonaperture radiation could be obtained by a relatively small amount of absorber material. It was thought that back-lobe radiation was due to the feed alone and that absorber could be used to readily eliminate this component. Unfortunately, this is not the case. It can be shown that reflections from the discontinuities in the lens cause significant back radiation that can be reduced only by completely covering the lens. These discontinuities are due to the method of construction of such lenses. Measurements have been taken of this back-lobe radiation, and its source has been located by placing absorber

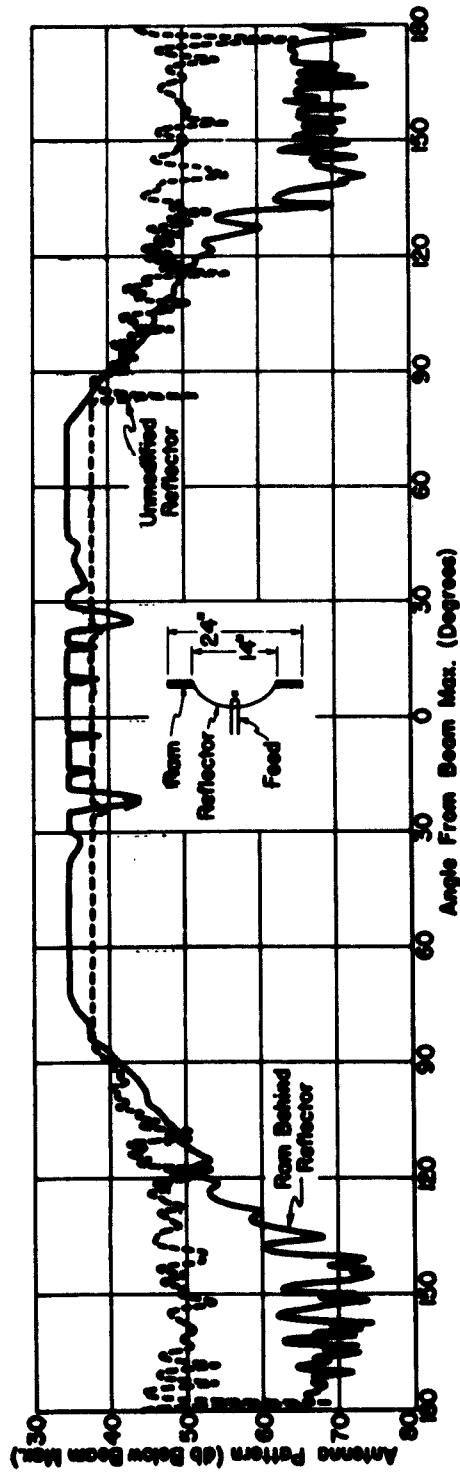


Fig. 2. E-plane backlobe reduction of 14" paraboloid reflector antenna

at various positions. It is found necessary to shield the lens completely in order to obtain adequate reduction in some particular direction. Reductions of 10-20 db in the back-lobe levels are readily obtained at angles greater than 60° from the main beam by use of RAM. A technical report is to be written describing in detail the reduction that can be obtained for back-lobes of the Luneberg lens.

C. Horn Antenna

A study of the horn antenna with regard to back-lobes has been initiated. Measurements on a horn antenna demonstrate that a large reduction in the back-lobe level in the E-plane can be obtained by the use of absorber. A pyramidal X-band horn $13\frac{1}{2}$ inches in length with a $9" \times 9"$ aperture was employed. A major portion of the observed diffraction is caused by the edges perpendicular to the E-plane since the electric field vanishes along the other two edges. Thus a large reduction in back-lobes is obtained when the edges perpendicular to the E-plane are shielded by absorber material. No significant changes is obtained in the H-plane in this case except in the region near 180° . No significant change is obtained in either plane when the edges perpendicular to the H-plane are shielded.

The use of the geometrical theory of diffraction as a method of determining the back-lobe structure of the horn antenna will be considered.³ The resulting calculations will be compared with measurements to determine the validity of this approach.

III. DESIGN OF NULLS IN THE FRESNEL ZONE

A method has been proposed that will yield a null in the Fresnel zone of an antenna by use of radar absorber material (RAM). This method is illustrated in Fig. 3 for a linear antenna. It was noted that the fields in the region just outside the absorber material would be zero. The total field is

$$E_t = E_{ANT} + E_{RAM}$$

where E_{ANT} = Antenna Field

E_{RAM} = The change in Field due to the radar absorber material.

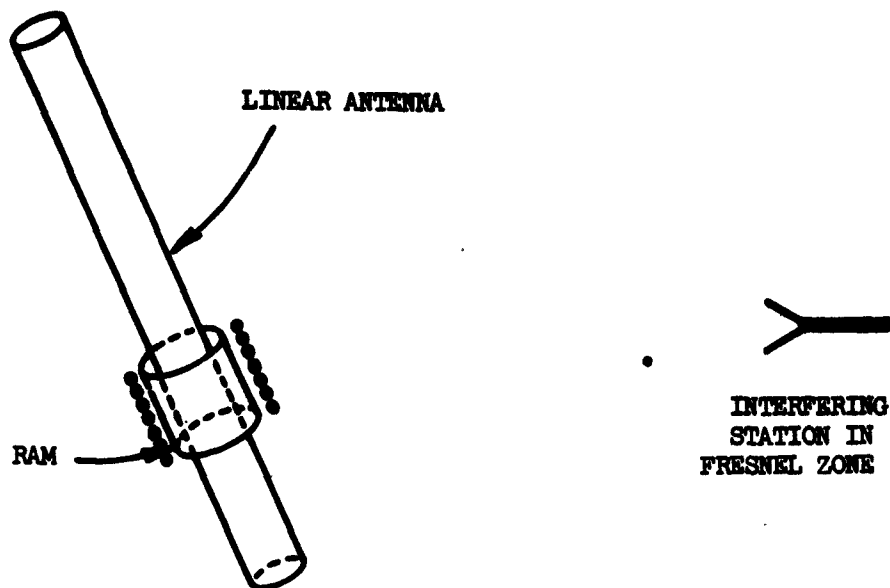


Fig. 3. Illustration method for obtaining nulls in the Fresnel zone.

Thus $E_{RAM} = -E_{ANT}$ on the absorber surface. This yields the appropriate aperture fields required to obtain the radiated fields due to E_{RAM} . If, at any point in space, these fields are equal in magnitude to E_{ANT} but displaced 180° in phase, a null will appear. This may be done in the Fresnel zone where nulls are not usually a characteristic, and in particular the null may be sufficiently wide to isolate a small antenna.

This concept has been verified theoretically using the computer program available for computing the fields of an antenna at any range. A Fresnel zone pattern of the circular aperture distribution $(1 - r^2)$ was first computed. The position of the null was selected, and the size and position of the absorber material required to obtain it were determined. Then the pattern of the combination was obtained using the computer program. The null was slightly displaced and not of adequate depth. These faults were readily eliminated by modifying slightly the original position and size of the absorber. The final depth of this null was 30 db below the original fields at this point, and the width of the null was $0.79\lambda \times 2.36\lambda$. One fault of this method was that in some cases the far-field side lobes due to the radar absorber material became dominant

and thus increased significantly the far-field side-lobe level.

A second point in the Fresnel zone was chosen to be nulled, and the process repeated. In this case the Fresnel-zone field had decayed to a smaller magnitude, and no new problems were noted in the far field. This second case was equally successful in producing the desired null, and in this case the null was 23 db below the original value and was $3.14\lambda \times 6.28\lambda$ in area. A report is being written which describes the details of the analysis and the use of this technique.

IV. EQUIPMENT

The investigation of undesired radiation on occasions requires measurement of very low levels. Although extremely low measurements are required only occasionally, they of course require special attention. It is, therefore, desirable to use equipment on which most measurements can be made quickly and with relative ease, but which requires only slight modifications for making the more difficult measurements of very low signals.

The equipment consists of a standard Antenna Laboratory pattern range using a 500 cps selective amplifier with a 4-cps passband. The input stages of the amplifier were placed in optimum condition. A 5-watt X-band klystron (tube type V-23) was used as a source. It was possible to measure a signal that is 65 db below the pattern maximum of the 14-inch parabola referred to in Section II. A. Since orders of magnitudes are of interest, the 14-inch diameter parabola is represented by a 14-inch diameter uniformly illuminated aperture which has a gain of approximately 31 db. Thus production-type measurements can be taken when the pattern level is not less than 35 db below the pattern level of an isotropic antenna located at the antenna site.

Reflections from nearby objects can become significant when the pattern level is about 10 db below the isotropic level. Although this has been determined experimentally, it would be desirable to study the permissible size, range, and radar cross section of nearby objects. This study would also have important RFI applications. The objects causing the present difficulty, consist of a pair of parabolas about 40 foot from the antenna test, were located and removed. There appears to be no additional scatterers of significance at the test site.

The equipment may be modified by placing a TWT amplifier (tube type Z-5259) in front of the detector. Now sensitivity is such that measurements 45 db below the isotropic level may be taken. Additional precautions are necessary when this arrangement is used. Chief among these are checks for (a) saturation of the detector, (b) leakage from waveguide joints, (c) previously unobserved scatterers, and (d) linearity.

V. CONCLUSIONS

The use of absorber material as a means of side-lobe reduction is demonstrated for three antenna types. For the paraboloid, significant reduction is obtained in the E-plane, whereas the H-plane is reduced only in the 180° region. In the case of the Luneberg lens, in which the feed back-lobes are low, the back-lobes appear to originate from the structural discontinuities of the lens proper. The principal source of back-lobe radiation for the horn antenna is the aperture edges perpendicular to the E-plane.

A method for the design of a null in the Fresnel zone of an antenna is discussed. The null is produced by a section of absorber of appropriate size and location in the antenna aperture.

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CATALOGUE FILE CARD

<p>Rome Air Development Center, Griffiss AF Base, N.Y. Rpt No. RADG-TDR-63-7. APPLICATION OF ELECTRO- MAGNETIC ABSORBING MATERIALS AS INTERFER- ENCE REDUCTION TECHNIQUES. Interim Engineering Rpt, 6 Sept 62, 11pp, incl illus.</p> <p>Unclassified Report</p> <p>The use of radar absorber material is being considered for reduction of radio-frequency interference (RFI). The study of side-lobe reduction is being applied to three antenna types: the paraboloid reflector, the Luneberg lens, and the horn antenna. A method is proposed for the design of a null in the Fresnel zone for the purpose of RFI reduction with a small antenna located in the null.</p>	<p>1. Antenna radiation patterns 2. Radio interference I. AFSC Project 4540, Task 454001 II. Contract AF30(602)-2711 III. Ohio State University, Antenna Laboratory, Columbus 10, Ohio IV. L. Peters, Jr., R.C. Rudduck, P.M. Russo V. In ASTIA collection</p>	<p>Rome Air Development Center, Griffiss AF Base, N.Y. Rpt No. RADG-TDR-63-7. APPLICATION OF ELECTRO- MAGNETIC ABSORBING MATERIALS AS INTERFER- ENCE REDUCTION TECHNIQUES. Interim Engineering Rpt, 6 Sept 62, 11pp, incl illus.</p> <p>Unclassified Report</p> <p>The use of radar absorber material is being considered for reduction of radio-frequency interference (RFI). The study of side-lobe reduction is being applied to three antenna types: the paraboloid reflector, the Luneberg lens, and the horn antenna. A method is proposed for the design of a null in the Fresnel zone for the purpose of RFI reduction with a small antenna located in the null.</p>	<p>1. Antenna radiation patterns 2. Radio interference I. AFSC Project 4540, Task 454001 II. Contract AF30(602)-2711 III. Ohio State University, Antenna Laboratory, Columbus 10, Ohio IV. L. Peters, Jr., R.C. Rudduck, P.M. Russo V. In ASTIA collection</p>	<p>1. Antenna radiation patterns 2. Radio interference I. AFSC Project 4540, Task 454001 II. Contract AF30(602)-2711 III. Ohio State University, Antenna Laboratory, Columbus 10, Ohio IV. L. Peters, Jr., R.C. Rudduck, P.M. Russo V. In ASTIA collection</p>	<p>1. Antenna radiation patterns 2. Radio interference I. AFSC Project 4540, Task 454001 II. Contract AF30(602)-2711 III. Ohio State University, Antenna Laboratory, Columbus 10, Ohio IV. L. Peters, Jr., R.C. Rudduck, P.M. Russo V. In ASTIA collection</p>
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